

Augmented Reality for Anatomical Education

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The use of Virtual Environments has been widely reported as a method of teaching anatomy. Generally such environments only convey the shape of the anatomy to the student. We present the Bangor Augmented Reality Education Tool for Anatomy (BARETA), a system that combines Augmented Reality (AR) technology with models produced using Rapid Prototyping (RP) technology, to provide the student with stimulation for touch as well as sight. The principal aims of this work were to provide an interface more intuitive than a mouse and keyboard, and to evaluate such a system as a viable supplement to traditional cadaver based education.

INTRODUCTION

Traditional computerised education software uses the window, icon, menu, pointing device (WIMP) interaction style. Although this works well with 2D work spaces, it can prove to be counter-intuitive when working with 3D environments, as 2D operations have to be used to manipulate 3D objects.

Augmented Reality (AR) allows a user to interact with virtual content in 3D space. AR is a development of Virtual Reality (VR) that allows the user to see both 3D computer-generated content and the real world concurrently in a composite image on a computer display. In AR the user is able to interact with both the real and virtual elements of the environment as though they were both situated in the real world. Azuma (1) defines an AR as an environment in which:

1. The virtual and the real are combined
2. Real-time interaction is possible
3. Real and virtual objects are registered in 3D space

The use of AR is compelling as it can allow for effective collaboration among users if the environment is shared; users can see both the virtual objects that they are manipulating and each other without obstruction. AR can also provide the user with effective positional cues because the surrounding real environment is constantly visible. AR provides the user with an interface that requires little learning as every physical interaction with an object has a predictable result as the virtual representation must follow the real object that it is attached to. AR has been evaluated for use in a diverse range of applications, including education.

Education in anatomy has changed dramatically over the last half-century. Traditionally anatomy has been taught through the dissection of cadavers; however this practice is not as widespread as it once was. This reduction is due to a number of reasons, including financial considerations and ethical issues (2). In schools, small animals such as rats and frogs were often used to teach simple aspects of anatomy. This practice too has decreased over recent years because of an increased recognition of animal rights issues. This has led to anatomy being taught in a variety of different ways, including Prosections, Problem-Based learning Scenarios (PBLs) or, more recently, computer systems derived from the Visible Human Project (3), such as the VOXEL-MAN project (4). Many anatomists, however, believe that cadaver dissection is still the optimal method of anatomy education. Cadaver dissection not only gives the learner knowledge of the shape and size of the organs, it gives them an appreciation of how individual organs are positioned relative to the rest of the body. Alternative methods exist for teaching

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anatomy. Many provide excellent opportunities for learning about individual organs, however, it is felt that the lack of presentation of spatial relationships can be a disadvantage relative to cadaver dissection. Cadaver dissection is also believed to promote self-directed learning, and teamworking. It also introduces students to death in a controlled manner (2).

Medical diagnosis is often carried out using images from medical scanning devices. In the past these images have been viewed sequentially by the practitioner, who had to interpret volumetric information from a sequence of 2D slices. More recently, scanning workstations have become available that can create 3D reconstructions of the data, using volume rendering and other techniques, which can allow for a much more accurate diagnosis. Such techniques have also been exploited for educational purposes. John and Lim (5) have previously provided a summary of such work.

While 3D approximations and reconstructions of medical images have been used for anatomy education, most systems have used the WIMP interaction style. Using an AR environment can allow a much more natural interaction with the data being represented, especially if some form of tactile interface can be used. Computer simulations and educational software can provide the user with a wealth of information about the object that is being studied; however a person's perception of an object is created from a combination of five senses.

In the work described in this paper we focus on visuals and feel. The addition of a tactile interface can help increase a user's immersion in an AR environment, especially if the physical form matches that presented in the AR environment.

Rapid Prototyping (RP) provides a method of rapidly creating patient-specific physical models of organs of interest. Models can be generated from a variety of data types, including medical scans. RP is the practice of taking 3D virtual models (usually a stereo lithography file format for CAD software) and creating a physical equivalent. RP machines can use either additive or subtractive processes. Additive RP machines construct models layer by layer, which are then attached to each other by a process such as gluing, or fusion using a laser. Subtractive RP machines start with a block of material that is then cut to shape using a laser or a similar device. The models tend to be made from a plastic material, although some machines may use paper, cardboard or metal. RP is now becoming more affordable as hardware costs fall and because companies such as Ambler (<http://www.expressprototyping.com>) and Inition (<http://www.thinglab.co.uk>) provide a bureau service so that the purchase of specialised equipment is no longer necessary. RP models can faithfully reproduce anatomy segmented from CT and other medical data and can even use pumps to circulate fluid, mimicking blood flow and permitting contrast media injections, with realistic guidance using through-transmission of light or real fluoroscopy. Useful surveys of most current uses of RP to assist medical applications are provided by Webb (6) and Gibson et.al. (7). In particular, they identify oral and maxillofacial surgery, orthopaedic applications, forensics science, prosthesis development and tissue engineering. Despite these wide ranging uses of RP models, the use of RP models for general anatomy teaching has not been previously reported.

This paper presents the Bangor Augmented Reality Education Tool for Anatomy (BARETA), which uses an RP model created from MRI data as a novel interface into an AR environment. BARETA aims to teach medical students about human anatomy, the current version of which focuses on the human ventricular system. Our hypothesis is that an AR approach can provide added value and new functionality to student learning about anatomy.

A list of requirements for the BARETA anatomy teaching tool platform was drawn up in collaboration with an anatomy lecturer based at Bangor University. It was decided that in addition to Azuma's requirements for an AR (1), BARETA must:

1. track a mobile viewpoint
2. track two physical objects (an anatomy model and a data interrogation tool)
3. be capable of rendering high resolution medical volume data in real-time
4. be suitable for use in a classroom environment
5. be easily moved between locations
6. impart the desired anatomical knowledge to the student

METHODS

The development of BARETA, designed to fulfil these requirements, is described in the remainder of this section.

In an effective AR system the location and orientation (pose) of objects in the real world must be known. As objects are likely to be in motion, a tracking system is required to ensure correct registration. Several different types of tracking system exist, many of which are suitable for use with AR systems. Often the choice of tracking system will depend upon the individual application. Factors affecting the choice of tracking system include the location at which the AR system will be used (indoor or outdoor), the range over which tracking is required, and budgetary requirements. Ideally for an AR system a 6 Degrees of Freedom (6-DOF) tracking system will be used. Such systems can track both the position and orientation of an object in 3D space relative to a fixed origin.

For tracking the anatomy model and the data interrogation tool in the BARETA environment a magnetic tracker was deemed suitable. Magnetic tracking devices do not require a line of sight between the transmitter and the sensor, therefore an object can be attached to a sensor without adversely affecting tracking; this also means that the position of a user's hands does not affect tracking accuracy. The magnetic tracker used was an Ascension miniBIRD 800 (miniBIRD) with two sensors and electronics units. The miniBIRD's tracking radius of about 36 inches from the transmitter is very small, however the user was not expected to move the physical objects very far and the objects' rotation is much more important in our application.

Viewpoint tracking could also have been carried out using magnetic tracking, however this would have limited the range of movement of the user's head too much, because it would have to be close to the origin of the magnetic tracking system, and therefore to the object. Instead, the system used for viewpoint tracking was the InterSense IS-1200 VisTracker (VisTracker). It allowed a wide range of tracking within an environment prepared with fiducial markers. Markers needed to be precisely placed for maximum tracking accuracy.

BARETA was run on a standard Intel Pentium 4 Windows desktop PC with 1GB of RAM and a high-end nVidia GeForce 8800GTX graphics card. This graphics card allowed for the use of fast hardware 3D texture-mapping of the volume data that was to be used for the system. Our primary display type was a standard computer monitor, although BARETA could be adapted for other displays.

An off-the-shelf Logitech Quickcam Pro 9000 USB webcam was used to provide the real part of the BARETA environment. It could capture at resolutions up to 1600×1200 pixels at 30 frames per second. Features of this camera included a capability to automatically adapt to a wide range of lighting conditions, auto-focus and face-tracking. The final two features were both disabled for use with our system as they could be detrimental to the registration of the system. The camera was attached to the VisTracker allowing the camera to be tracked, and therefore ensuring that correct registration was maintained as the camera was moved. During our user study the camera was positioned behind the user pointing towards the screen.

The Visualization Toolkit (VTK, (8)) was used as the rendering library for the system, allowing the use of a diverse range of data types and rendering options, including video streams from a webcam and a variety of volume rendering methods. VTK was used to perform volume and surface rendering of the data of an MRI scan of a human head. The surface data was derived from a segmentation of an MRI scan of a human head: A live subject was scanned using the 3 Tesla MRI scanner at Bangor University's School of Psychology at a resolution of 384×384×220 with a voxel spacing of 0.625×0.625×0.7mm. The segmentation was performed using the ITKSnap software (9). Additionally VTK displayed arrows and text to highlight important areas.

An RP model acts as the interface to the AR system. The RP model, created using a 3D printer was derived from the surface data produced during the segmentation of the ventricles. The plastics used for such models are quite robust and were therefore suitable for use in a classroom environment. A bureau service was used to produce our models.

The use of an RP model has several potential advantages over generic anatomy mannequins, in particular the use of patient specific data to highlight natural anatomical variations among different people, and for the on-screen renderings shown to exactly match the object that the user is holding. This also allows the effects of various diseases to be shown. New variations and cases would be very easy to add as no

additional tooling needs to be made - only data of the object of interest is needed. This project is the first to apply RP to anatomy education in this way.

The RP model was fitted with a miniBIRD sensor to allow BARETA to track it and was used to manipulate a volume rendering of a human head. The dataset used for the volume rendering was the same dataset as that used to produce the RP model, allowing the volume rendering to be registered with the RP model. Rather than rendering only the segmented region, the entire head was volume rendered. The surface model of the ventricles that was used to create the RP model was also visualised. The surface rendering was also performed by VTK; the surface was rendered in such a way that it was registered with the ventricles present within the volume rendering. The volume data and surface data were placed into an assembly, which allowed both representations to be manipulated using a single transformation. This also ensured that correct registration was retained when transformations changed.

Two transformations were applied to the assembly to ensure that registration was correct between the RP model and the on-screen rendering. The first transformation changed the pose of the centre of rotation of the assembly to reflect the position of the sensor within the RP model. The second transformation scaled the assembly to match the size of the RP model on-screen.

A piecewise transfer function was used during volume rendering to prevent air from being displayed, and therefore allowing the organ of interest to be viewed. All voxels with a value of less than 2 were made fully transparent, whilst the remaining voxels were made completely opaque (Figure 1 left), showing the exterior of the volume data. This works well for viewing the exterior of the head alone; however it does not allow the surface rendering of the ventricles to be viewed. Therefore in order to see the ventricles the way in which the volume was viewed had to be changed.

The first way in which the volume could be viewed in a way that allowed the ventricles to be seen was by using clipping plane (Figure 2 left) and slab rendering (Figure 2 middle) features. The clipping plane and slab rendering could be arbitrarily manipulated using the data interrogation tool (second miniBIRD sensor), to which a small piece of paper was attached to represent the orientation of the plane. These two features enable the user to cut away parts of the volume rendering, allowing portions of both the exterior and interior to be viewed. This helps to establish the spatial relationship between interior and exterior features.

The second way in which this was accomplished was by using a different transfer function, one that reduced the opacity of the volume rendering to a level at which the ventricles could be seen, yet still allowing the volume rendering to remain visible (Figure 1 middle). A transfer function could have been chosen to render the volume in a variety of colours that could have enhanced certain details (Figure 1 right); however a simple greyscale function was chosen. This meant that the appearance of the volume rendering should match the colouring that would be encountered when viewing the MRI data as slices, as is currently the case in medical diagnosis. This also allowed for a large contrast between the volume rendering and the red colour chosen for the ventricles surface rendering.

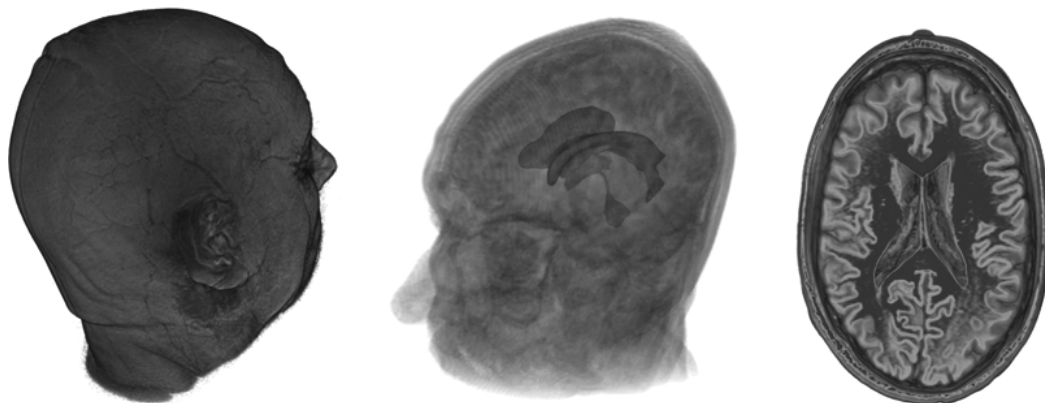
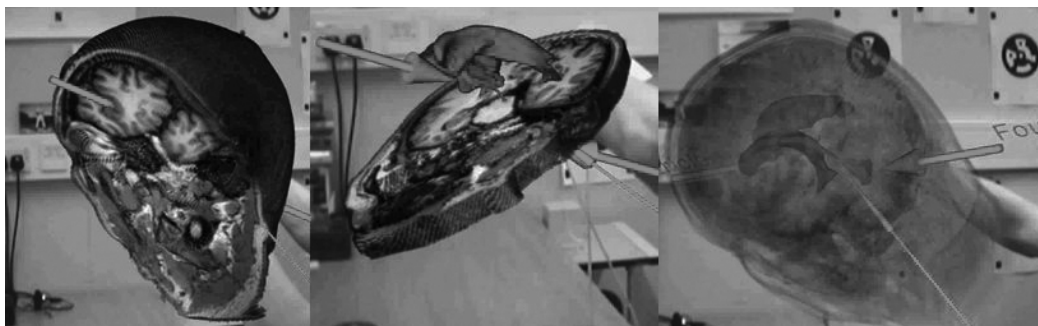


Figure 1. A volume rendering of the human head data set used in the sample anatomical lesson. Data source: MRI, Philips 3T Achieva MR scanner, 384×384×220 (left). The surface model of the ventricles can be seen through the transparent volume rendering of the head (middle). A clipping plane through a volume rendering with a pseudo-colour transfer function applied (right).

Figure 2. Screen shots of BARETA in operation showing the clipping plane (left), slab rendering (middle) and transparency (right)



The inclusion of the ventricles surface model within the whole head volume rendering is useful as a reference to the location of the ventricles; however the ventricles have many detail features that are important for students of anatomy to learn, which may not be obvious from this rendering alone. To help users to identify key features of the ventricles an arrow was used; this was coloured green to contrast with the greyscale of the volume rendering and the red of the ventricles. Eight features were labelled. The eight features were: the third ventricle, the fourth ventricle, the anterior horn, the inferior horn, the cerebral aqueduct, the posterior horn, the right lateral ventricle and the collateral trigone; the change of arrow position and text label was activated by the user pressing a number key on the keyboard in the range 1–8.

From the aforementioned features our anatomy lesson was constructed. The anatomy lesson consisted of three different steps, each providing the user with a different way to view the ventricular system. During each step the clipping and slab rendering features could be enabled and disabled by the user with a single keystroke. Transitions to successive steps were activated using a press of the space bar. The steps were as follows:

1. The volume is rendered using a transfer function which makes the entire head opaque, and the surrounding air transparent. The arrow is visible; however the associated label is not.
2. The volume rendering gradually becomes more transparent, allowing the surface rendering of the ventricles to be viewed within. Labels associated with the visible arrows appear (2).
3. The volume becomes completely transparent, allowing the user to look at the surface rendering, arrows and labels.

This lesson allowed the user to view the head and the ventricles at his or her own pace, and explore the head by moving a tracked model of the same ventricle data that is being viewed onscreen, and to interrogate this data using a tracked tool held in the other hand. The only restrictions placed on the user's movements of the RP model were those imposed by the tracking devices.

RESULTS

Pilot user studies were carried out at Bangor University's School of Healthcare Science and at Connah's Quay High School to evaluate the usefulness and usability of BARETA. The results from these two user studies provided insight into the areas of BARETA that could be improved; improvements were then made to reflect what had been learnt.

Our main user study was carried out at the School of Medicine at Keele University. Thirty-four first year medical students – twelve male, twenty-one female – took part in the study. Students were divided into groups of four to six people and rotated through four stations: BARETA (Figure 3) and three conventional cadaver dissection activities. During the BARETA session, each student in the group was given the opportunity to use BARETA and then fill out a questionnaire. The questionnaire asked the students a number of questions relating to the usefulness and usability of BARETA. Questions were posed both positively and negatively and the result averaged to avoid any bias caused by the wording of the question. The questionnaire presented used a five-point Likert scale. For analysis purposes we subsequently assigned a value of five to the response "strongly agree", four points to "agree", three points to "neutral", two points to "disagree", and one point to "strongly disagree". Also included was space for the students to record



Figure 3. A student using BARETA at Keele University, demonstrating the clipping plane in use

additional comments. The formula $Answer = \frac{(Positive + (6 - Negative))}{2}$ was used to combine the result of a positively posed question with a negatively posed one, where a result of 1 was the worst and 5 was the best. This provided ten separate lines of enquiry that could be evaluated. The lines of enquiry were as follows.

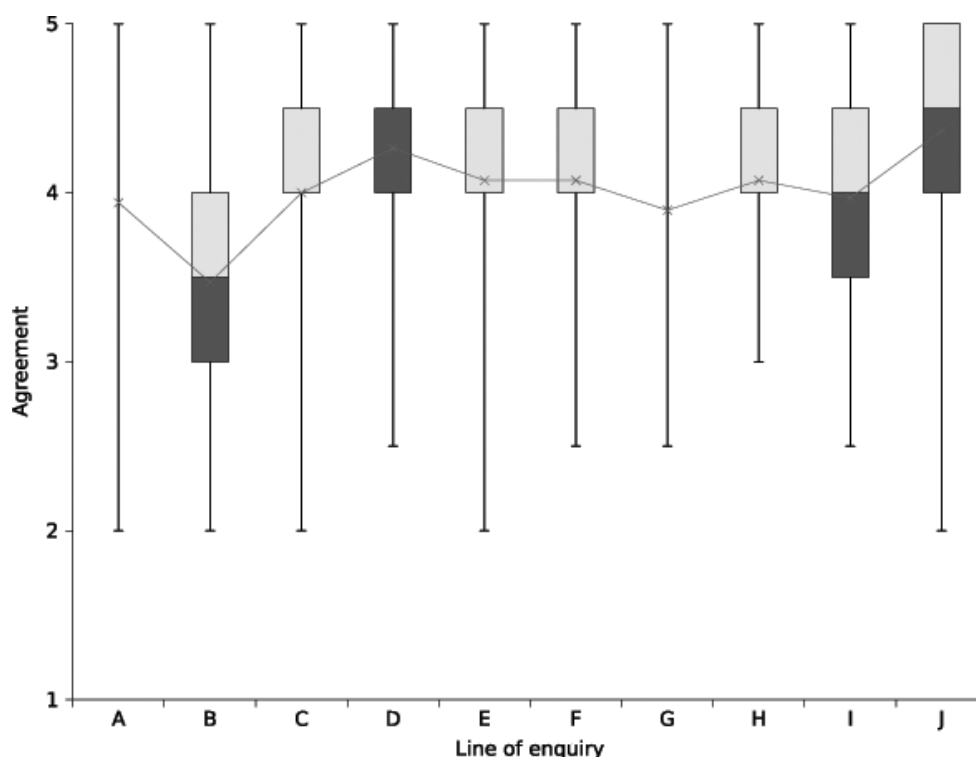
- A. The system was easy to use
- B. Co-ordinating the two sensors was easy
- C. The transparency feature was useful
- D. The clipping plane was useful
- E. The slab rendering feature was useful
- F. Using the plastic model as an interface was more intuitive than using a mouse and keyboard to move the onscreen image
- G. The arrows and labels were well positioned
- H. Using a physical representation of the ventricles made the system easier to use
- I. The frame rate of the system was good
- J. The system helped me to understand the shape and location of the ventricular system

A chart of results from the user study is presented in Figure 4.

The most important result for our hypothesis was that the students found that BARETA helped them to understand the shape and the location of the ventricles within the human head (Line J). All but two of the students recorded a score of 4 or greater for this line of enquiry. A mean of 4.3 and a median of 4.5 suggest that the students' agreement is quite strong.

Ease of use of BARETA is another important area of questioning. Several questions dealt with this. Line of enquiry A asks users if they found BARETA easy to use. Although results ranged from 2 to 5, a mean of 3.9 and a median of 4 suggest that most of the students found that the system was easy to use. Line of enquiry F also relates to ease of use; this pair of questions asks the students if they found that using the plastic model as an interface was more intuitive than using a keyboard and mouse interface. The results

Figure 4. A summary of the results from the user study held at Keele University



here were also positive, with a mean of 4.1 and a median of 4 strongly suggesting that the students found that using the plastic RP model as an interface was more intuitive than using a keyboard and mouse interface. Line of enquiry H was similar, and showed almost identical results. Another aspect of BARETA for which we sought opinions was the inclusion of the novel viewing features. Line of enquiry C asked the students whether they felt that the transparency feature was useful. The majority of the students agreed that this feature was useful, showing a mean and median of 4. The remaining students disagreed. Another novel feature that was demonstrated to the students was the clipping plane feature. Line of enquiry D asked the students for their opinions on this feature. Most of the students found that this feature was useful, recording a mean of 4.3 and a median of 4.5. The lowest score was 2.5, suggesting that none of the students strongly disagreed. The final novel feature that we demonstrated to the students was the slab rendering feature, which was dealt with by line of enquiry E. Once again opinions were favourable with a mean score 4.1 and a median score of 4 suggesting that most of the students found this feature useful.

As the use of the clipping plane and slab rendering features required the coordination of two tracked physical objects we wanted to see how easy the students found co-ordinating the two sensors, which was addressed by line of enquiry B. The results reveal that not all of the students found that the two sensors were easy to co-ordinate although a mean and a median of 3.5 suggest that several of the students found the two sensors easy to co-ordinate. The maximum score was 5 and the minimum 2, suggesting that a few of the students found co-ordination difficult, but not beyond their capability.

Line of enquiry G asked the users for their opinions on the way in which the arrows and labels were displayed. Most of the students found that the arrows and labels were well positioned, with a median score of 4 and a mean of 3.9. The remaining line of enquiry (Line I) asked the students how they felt about the frame rate of BARETA. A mean and a median of 4 suggest that the students were satisfied with the frame rate of the system; only two students recorded a score of less than 3.5 for this line of enquiry.

The standard deviation for each line of enquiry was also calculated, and can be seen in figure 5. The minimum standard deviation for a line of enquiry was 0.56 and the maximum 0.83 suggesting that although the students had differing opinions about each aspect of the system, they did not disagree by a large amount.

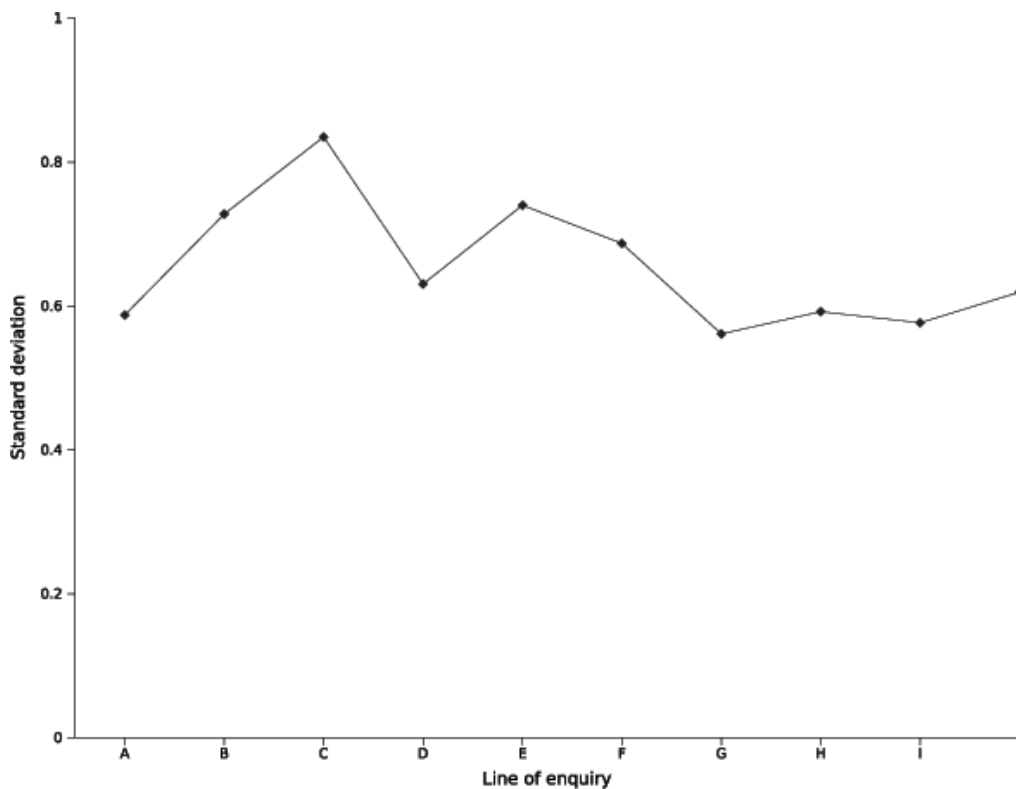


Figure 5. A chart showing the standard deviation for each line of enquiry at Keele

As students in later groups had some experience with dissecting a cadaver immediately prior to using BARETA, an opportunity arose to see how opinions on the system changed as a student had carried out more dissection of the brain. To investigate this we took a mean value from each group for each line of enquiry which allowed us to make a comparison (Figures 6 & 7). It would appear in general that the

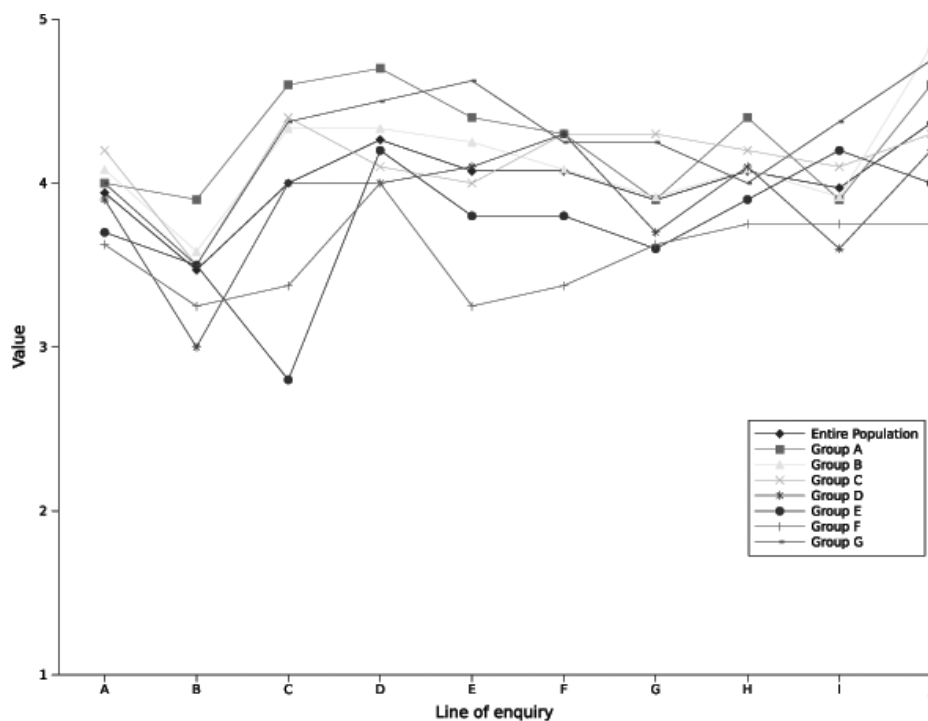


Figure 6. A chart displaying the mean result for each group

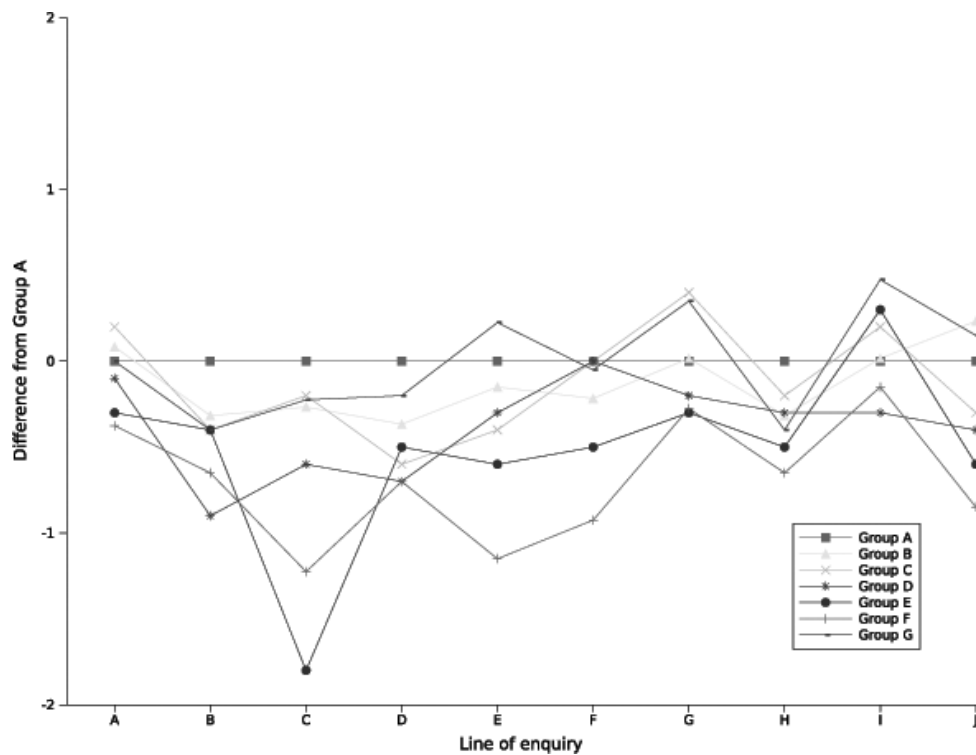


Figure 7. A chart showing each group's difference in mean from that of group A

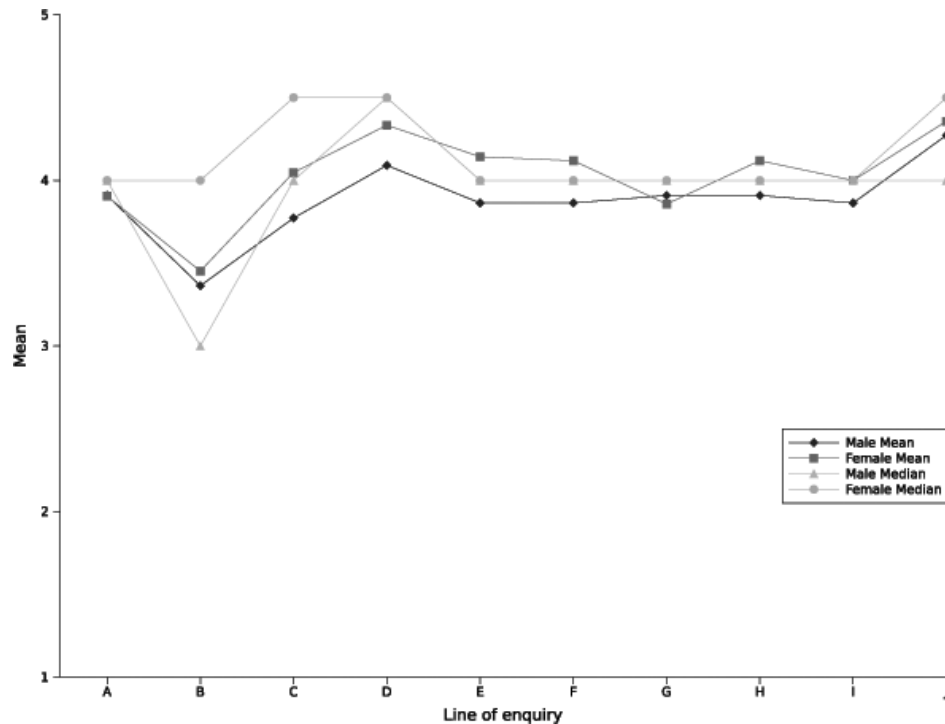


Figure 8. A chart displaying the mean and median results, comparing the responses of males and females

students' opinions of BARETA do change slightly as they carry out a real dissection. With the exception of group G, each successive group records a slightly lower mean for each line of enquiry. The line of enquiry featuring the largest difference is line C, asking about the usefulness of the transparency feature. This difference could also be attributed to small sample sizes (groups consisted of between four and six students).

The difference could also be attributed to some groups containing mainly female students and others containing mainly male students: Males are conventionally assumed to have better visuo-spatial abilities than females.

To investigate the effect of gender on a student's perception of BARETA we calculated the mean and median score of each line of enquiry for the two gender groups, the results of which can be seen in Figure 88. The difference between the mean score of the two groups is no greater than 0.28 for any line of enquiry; however the median shows differences as great as 1, although in all but three of the lines of enquiry it is identical. It is interesting to note that the male participants found co-ordinating the two sensors more difficult than the females.

The result of our user study suggests that the students did find that BARETA helped them to understand the shape and the location of the ventricular system. The perception of the usefulness of BARETA's novel viewing features – transparency, clipping plane, and slab rendering – was also important as these contributed to the effectiveness of BARETA as a learning aid. Many of the students felt that these features were useful, especially the clipping plane. Our user studies also assessed how easy to use BARETA was, and the utility of individual features. Some users felt that using the system could be a little difficult; however this was potentially caused by the positioning of the camera providing the real world scene, which was not always pointing in the user's view direction. Another advantage identified by the students was that they could use BARETA at any time and thus it would be invaluable for revision. Time in the dissection room is very scarce and subject to the availability of a cadaver.

BARETA presents some exciting opportunities for future development. The creation of lessons about other regions of the human body is also possible given relevant scan data and a segmentation that produces data suitable for the production of an RP model. BARETA could also be used to visualise more complex anatomy with some adaptation. For instance the function of the elbow joint could be illustrated using separate RP models of the upper arm and the forearm that meet at the elbow. This would require the use of two tracking sensors (one for the upper arm, one for the forearm), and software to calculate the movement of the muscle as the elbow joint is manipulated.

Cadaveric dissection has long been the gold standard in gross anatomy. This paper has presented the development of BARETA, a system that aims to act as an effective supplement to cadaveric dissection. Although the system is effective in conveying information about anatomy it is not yet able to fully replace cadaveric dissection. Although both visual and tactile representations of anatomy are presented, it cannot at present reproduce all of the sensations that cadaveric dissection can.

DISCUSSION

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